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Composite Thin-Disk Laser Scaleable to 100 kW Average Power Output and Beyond

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Composite Thin-Disk Laser Scaleable to 100 kW Average Power Output and beyond

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Abstract

By combining newly developed technologies to engineer composite laser components with state of the art diode laser pump delivery technologies, we are in a position to demonstrate high beam quality, continuous wave, laser radiation at scaleable high average powers. The crucial issues of our composite thin disk laser technology were demonstrated during a successful first light effort. The high continuous wave power levels that are now within reach make this system of high interest to future DoD initiatives in solid-state laser technology for the laser weapon arena.

Introduction

The interest and motivation to press forward with laser weapons is emerging as a compelling national need, as articulated in a report recently issued by the High Energy Laser Executive Review Panel (HELERP). The HELERP report addresses near-term needs, strategic vision, and programmatic balance for a vibrant national effort in laser weapons. Solid state lasers are, for the first time, being actively considered as a candidate for the KILL weapon; (solid state lasers have previously only regarded in supporting roles for tracking the missile and for atmospheric correction.) Perhaps most importantly, the national committee has affirmed that laser weapons are to play a critical tactical role for the warfighter in the 21st century. The key attributes of HEL weapons (not otherwise available) are the ability: to engage high-speed maneuverable targets with short reaction time, and to provide graduated (less than lethal) effects when required. The thin disk laser design presented here meets the requirement for a future laser weapon of high average power and beam quality. It is a side pumped light-guide/gain-medium diffusion bonded composite that is strikingly robust and resolves prior difficulties with high average power pumping/cooling and the rejection of amplified spontaneous emission (ASE). The crucial design ideas were recently proven experimentally. In contrast to high power rods or slabs, the one-dimensional nature of the cooling geometry and the edge-pump geometry scale gracefully to very high average power.

The Thin Disk Concept

Thin disk or active mirror configurations have recently been demonstrated at cw output powers exceeding 1 kW with the promise of very high beam quality. Today, the dominant development of this type of laser is being pursued at the University of Stuttgart in a group headed by Prof. Adolf Geissen[1]. The fundamental idea of the approach, which enables the generation of high average power with high beam quality, is illustrated in Figure 1 where it is seen that the thermal gradients in the laser sample are arranged to be parallel to the laser radiation propagation direction.

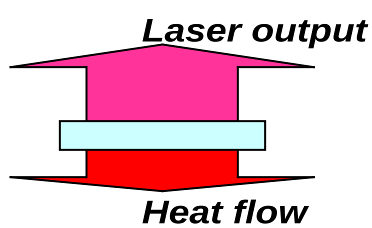

Figure 1- In thin disk or active mirror configuration lasers, the thermal gradient is arranged to be parallel to the laser propagation direction to avoid phase aberrations on the laser beam.

By keeping the thermal gradients parallel to the beam propagation direction, thermal aberrations cannot impart a phase aberration on the laser beam. To understand the average power scaling potential of this approach one then needs only consider the maximum thermal power that can be generated in the laser crystal without fracture. In a first approximation, the maximum laser output power that can be generated is proportional to the maximum thermal power dissipation that can be handled by the laser crystal. The laser output power per unit area P_{laser} is proportional to the fracture strength of a thin disk, which varies inversely as the thickness of the disk, which leads to the following scaling law,

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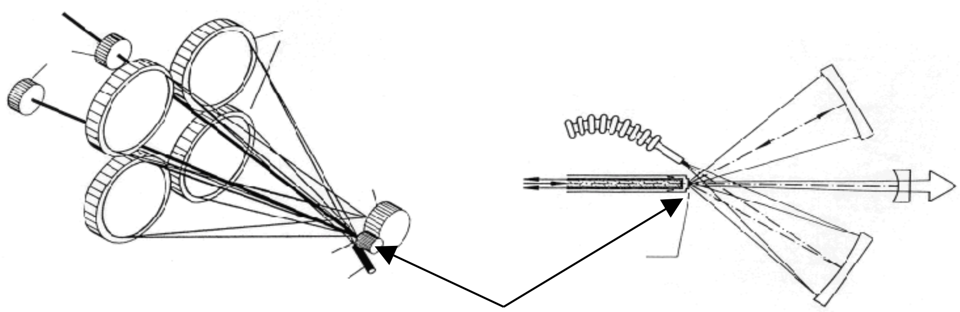
where t is the thickness of the thin disk. So, to maximize the average power capability one is driven to use very thin disks. This in turn drives one to develop multipass pump geometries because the use of thin disks implies very short pump absorption distances. In the very thin gain samples necessary to avoid fracture under intense pumping, the pump beam is re-imaged through the sample up to 16 times in the Stuttgart approach to increase the net absorption path. The very complicated pump geometry (figure 2) that this necessitates, and the obvious limitations to high average power scaling that it imposes, are issues that our thin disk concept recognizes and addresses.



Thin disk gain element

Figure 2- Thin disk geometry developed by Stuttgart group in which the pump radiation is multi passed through the thin disk sample to increase absorption.

The growth of ASE is another feature of the presently pursued Stuttgart thin disk technology that limits its average power scaling potential. Because the thin disk laser gain has to be sufficient to support efficient lasing in its thin direction, the transverse size of the gain region is limited due to the onset of parasitic lasing as shown in Fig. 3. The main reason for this sensitivity to ASE in the presently pursued Stuttgart thin disk approach, is the large solid angle that is confined by total internal reflection (TIR) at the top surface of the gain element. Due to TIR at the top surface, very long path rays can be confined within the gain loaded sample and effectively compete against the extracting laser beam for the gain media's stored energy. Our composite thin disk concept recognizes and addresses this issue.

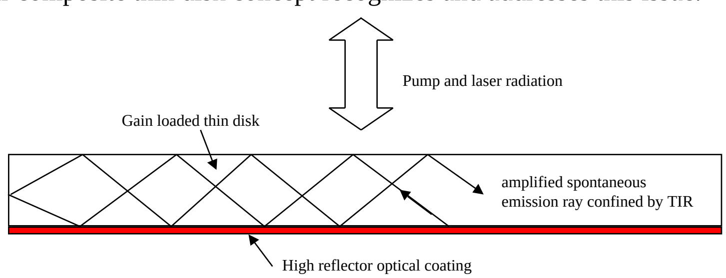


Figure 3- The thin disk architecture being pursued by the Stuttgart group is sensitive to ASE and parasitic lasing because of the large solid angle confined at the YAG-air interface.

The Composite Thin Disk Path to High Average Power Laser Weapons

Figure 4 depicts the basic thin disk approach we have begun to develop, which enables average power scaling of the thin disk concept to the 10kW average power level from a single contiguous aperture. The LLNL approach differs significantly from the Stuttgart approach in that on top of the thin disk gain loaded layer there is an index matched undoped layer that is attached using diffusion bonding. LLNL has taken a lead position in exploiting this diffusion bonding technology to manufacture composite laser samples for both improved optical and thermal performance of laser systems[2]. The purpose of the undoped layer is two fold. First, it provides for side-pumping the thin disk using a transverse or side-pumping geometry by functioning in the same way that the outer cladding on a double-clad fiber laser does. Second, it allows

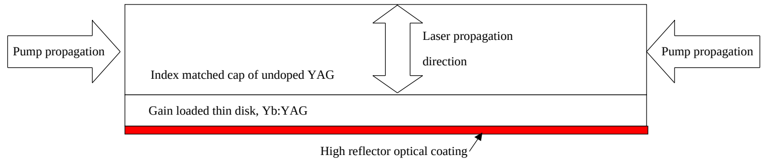


Figure 4- The LLNL thin disk concept uses an undoped cladding layer diffusion bonded to the thin disk layer that is index matched to the thin disk. The undoped layer serves the dual function of allowing ASE rays to escape from the top surface of the thin disk as well as serving as a pump delivery-cladding region.

ASE rays that are traveling upward in the gain-loaded portion of the structure to freely propagate out of the gain-loaded region and into the undoped region. By properly adjusting the thickness of the capping layer, it is possible to greatly reduce the maximum trapped path length of ASE rays in the gain loaded portion of the composite laser element, and so substantially reduce the impact of ASE on the gain loaded structure. Another important advantage provided by the isothermal, undoped layer is that of providing a stiff backbone resisting mechanical distortions. To prevent re-circulation of the ASE, the edges of the device are prism-like and effectively re-direct the ASE away from the gain layer. Indeed, the isolation of gain between ASE limited sub-apertures can be accomplished by prismatic grooves the thickness of the gain layer. An array of these sub-apertures can be arranged in a hexagonal close pattern as is shown in the 100 kW class laser weapon concept of figure 5.

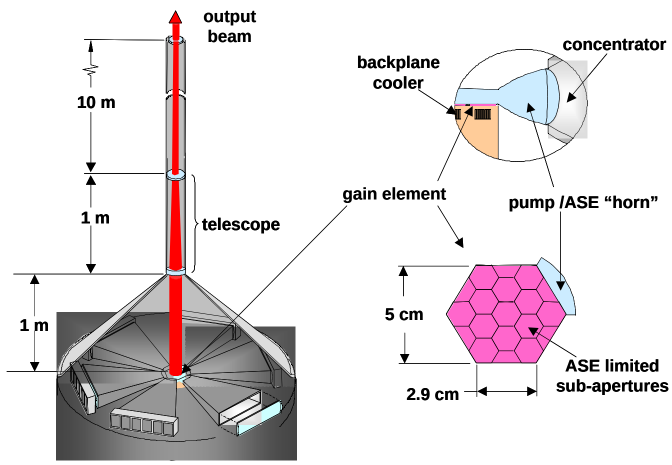


Figure 5- Conceptual design for a 100 kW class laser weapon. The Yb:YAG gain sheet is the same as in our experimental prototype (200μm) so the heat rejection intensity does not change. To augment pumping, the thickness of the undoped cladding is increased proportionately to the laser aperture dimension. The grooves isolate the ASE limited sub-apertures. The 10x telescopic resonator provides the large TEMoo mode desired and relies on the high cw damage threshold of the output optics.

HiBriTE First-Light and Recent Experimental Results

Using the sample configuration shown in Fig. 6, the HiBriTE project team has achieved first light from the experimental apparatus shown in the inset photograph. Pump delivery into the end of the undoped YAG-Yb:YAG composite element is achieved using a radiance conditioned laser diode array and a lens duct[3]. We have achieved a laser power of 260 watts at low duty factor and have used this data to anchor our laser modeling codes. Figure 7 presents the results of our energetics modeling code overlaid with actual data from the apparatus shown in Fig. 6. Two designs of the Yb:YAG/YAG composite gain element differing in length (6 mm and 12 mm) were fabricated by Onyx optics, the company we work with on diffusion bonding. Strong excitation and cooling of the thin laser gain medium within the 1.5-mm thick by 3-mm wide light trap was demonstrated, and was found to be consistent with predictions. The HR coating on the gain element must reflect the pump wavelength at a broad range of angles and simultaneously reflect at the

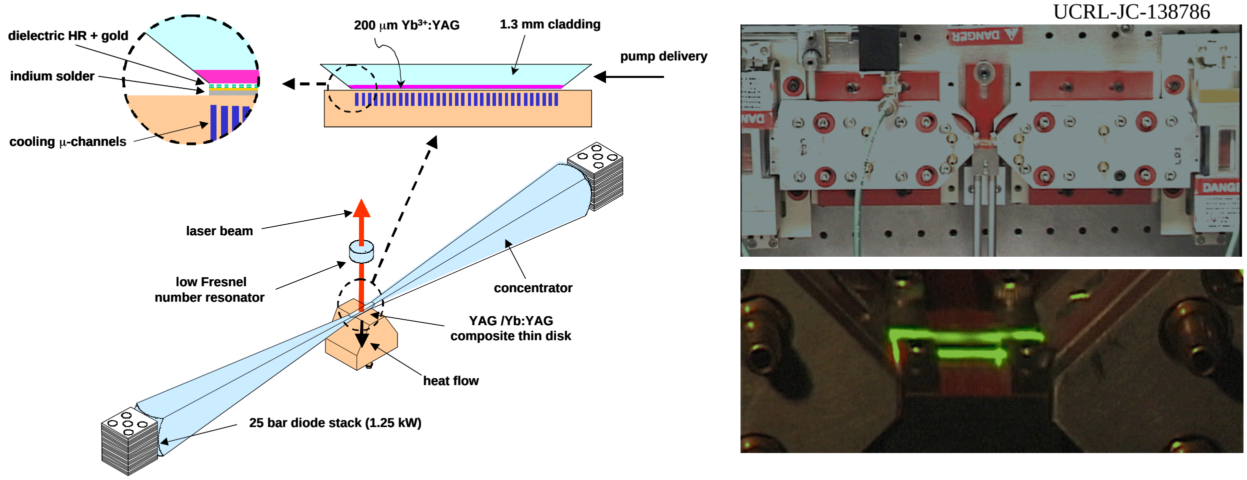


Figure 6 Two micro-lens-conditioned 25-diode stacks are concentrated by lens ducts and inject pump light into the edges of a composite gain medium soldered to the cooler in the center. Hardware photo inset.

laser wavelength. The efficacy of the heat removal using our first generation cooler was tested by the prototype. Calorimetric data (coolant flow rate and temperature rise) under continuous diode pumping showed that we reached a heat dissipation rate of 1.1 kW/cm^2 at the surface of the cooler. This maximum heat flux attained was very close to that predicted by our design calculations and required to operate as a scaleable system. Our one-dimensional ASE model was consistent with the fluorescence distributions observed at the pumping level used in these initial experiments. The fluorescence profiles were in accord with the source distribution calculated using our ray trace model.

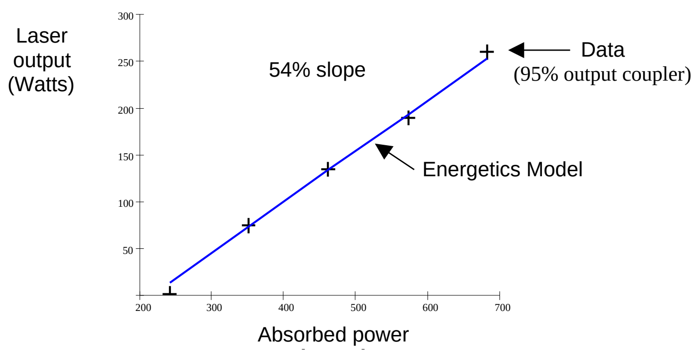


Figure 7 Laser output data plotted against the absorbed power measured is in excellent agreement with our quasi-three level energetics model. Note the high slope efficiency. Data was taken at 1% duty factor.

References

[1] A. Giesen, H. Hugel, A. Voss, K. Wittig, U. Brauch, H. Opower, “Scalable Concept for Diode-Pumped High-Power solid-State Lasers”, App. Phys. B, 58, 365-372 (1994).

[2] R.J. Beach, S.B. Sutton, J.A. Skidmore, and M.A. Emanuel, “High Power 2 mm wing-pumped Tm:YAG laser”, Technical Digest for 1996 Advance Solid State Lasers, p 249 (1996).

R.J. Beach, E.C. Honea, S.B. Sutton, C.M. Bibeau, J.A. Skidmore, M.A. Emanuel, S.A. Payne, P.V. Avizonis, R.S. Monroe, and D.G. Harris, “High-Average-Power Diode-Pumped Yb:YAG Lasers”, In Advanced High-Power Lasers, Marek Osinski, Howard T. Powell, Koichi Toyoda, Editors, Proceeding of SPIE Vol. 3889, pp. 246-260 (2000).

[3] Theory and Optimization of Lens Ducts R.J. Beach, Applied Optics 35, pp. 2005-2015 (1996).

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